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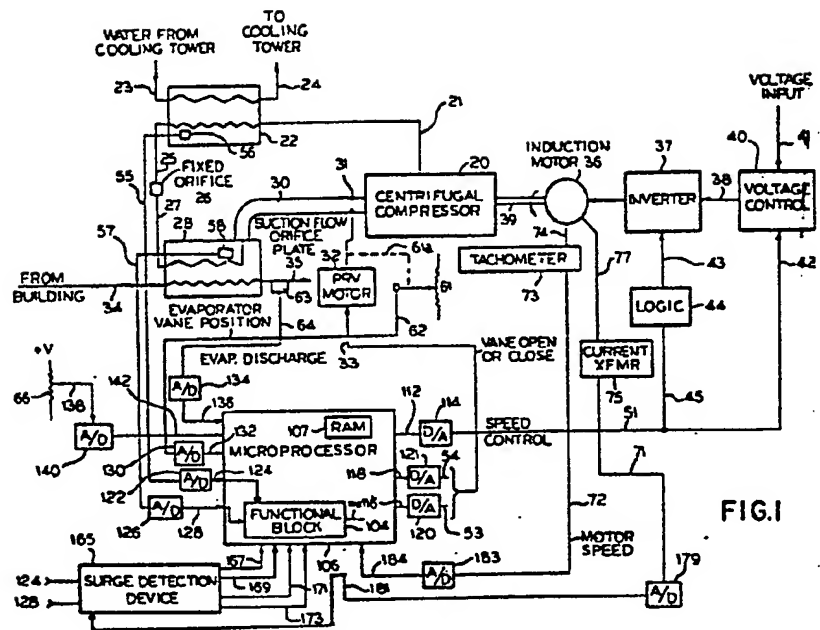(51) Int. Cl.⁴: **F 04 D 27/02**
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(54) **Self-optimizing centrifugal compressor capacity control.**

(57) A self-optimizing, capacity control system for a refrigeration system including a compressor (20), a condenser (22), and an evaporator (28), all connected in a closed refrigeration circuit is provided. The compressor includes a plurality of adjustable inlet guide vanes (31), a motor (32) connected to regulate the inlet guide vanes position and an electrical speed motor (36) connected to drive the compressor. The self-optimizing capacity control system includes a microprocessor (106) responsive to continual measurements of a PRV signal, a compressor head signal, a motor current signal and a motor speed signal for determining both the compressor speed and the position of the inlet guide vanes to define a current operating point in an initial surge surface array stored in a random-access memory (107). The microprocessor will initiate a "learning" mode in which the compressor motor speed will continually be decreased incrementally and the PRV will be moved to a more open position until an operating point is found where the compressor is surging. The microprocessor will update the initial surge surface array stored in the random-access memory with the latest surge conditions. Then, the microprocessor will initiate an "operating" mode in which the PRV are moved to a position responsive to a temperature error signal related to the difference between the chilled water temperature and the temperature set point and the compressor speed is set a safety margin away from the surge speed. In this manner, the microprocessor automatically regulates both the adjustable inlet guide vanes and the compressor speed in response to the continually updated "learned" chiller surge surface so as to realize minimum overall chiller energy consumption.

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FIG.1

SELF-OPTIMIZING, CAPACITY CONTROL SYSTEM FOR INVERTER-DRIVEN CENTRIFUGAL COMPRESSOR BASED WATER CHILLERS

Description

5   1.   Field of the Invention

This invention relates generally to refrigeration systems and more particularly, it relates to a self-optimizing, capacity control system for inverter-driven centrifugal compressor based water

10   chillers wherein adjustable inlet guide vanes and compressor speed are both automatically regulated in response to a continually updated "learned" chiller surge surface so as to realize minimum overall chiller energy consumption.

15   2.   Description of the Prior Art:

In the art of inverter-driven chillers, it is generally known that the most efficient operating conditions are met when the chiller is operating at an operating point which has the combination of the lowest

20   compressor speed and more open PRV position. However, the surge surface of the chiller restricts the degree to which the lowest speed and larger vane openings combination can be established. Thus, it should be clear that the objective of capacity control is to operate the

25   chiller at the lowest, surge free, compressor speed possible, but yet still supplies the load and head requirements. In certain prior art attempts, approximations to the chiller surge surfaces are factory set by means of pre-stored surge surface equations contained in

30   a capacity control unit. Since the surge surfaces for a particular chiller are not constant all the time and changes under certain conditions due to factors such as tube cleanliness, compressor aging, and drifts in

transducers or sensors used for detecting PRV position, condenser pressure, and evaporator pressur , the use of constant pre-stored surge surface equations do not take into consideration these varying conditions.

5   It would therefore be desirable to provide a self-optimizing, capacity control system for inverter-driven centrifugal compressor based water chillers which continually adjusts itself for varying conditions affecting the surge surfaces so as to operate at 10 minimum overall energy consumption.

U. S. Patent No. 4,151,725 which issued on May 1, 1979 there is disclosed a capacity control system wherein the compressor head value was inferred from the difference between the temperature of liquid refrigerant leaving the condenser and the temperature of the saturated refrigerant leaving the evaporator. This temperature difference was utilized with the control system to regulate both the means for adjusting the position of the guide vanes and the means for driving the compressor. 20 However, the assumed linearity of the function between the isentropic compressor head parameter Λ and the difference between the condensing and the evaporating refrigerant temperatures was not to be entirely accurate over the system operation, especially at light loads and 25 at low heads.

In U. S. Patent No. 4,282,719 which issued on August 11, 1981, there is taught a capacity control system having a more accurate indication of compressor head which, even at light loads and low heads, could be 30 determined by a signal that is a function of the expression $(P_{cd}-P_{ev})P_{ev}$. The numerator of this

ratio is derived from the differenc between the condenser absolute pressure P_{cd} and the evaporator absolute pressure P_{ev}. The denominator of this ratio signal is derived from the evaporator absolute pressure
5 P_{ev}.

In U. S. Patent No. 4,546,618 which issued on October 15, 1985, there is shown a capacity control system for inverter-driven centrifugal based water chillers which includes a microprocessor responsive to
10 continual measurements of a PRV signal, compressor head signal and suction flow signal for regulating both the inlet guide vanes and compressor speed. In another embodiment of this patent, the compressor head signal is replaced with an actual motor speed signal of the com-
15 pressor. Consequently, the microprocessor in the second embodiment is responsive to the PRV signal, motor speed signal and suction flow signal for regulating both the inlet guide vanes and compressor speed.

However, the three above patents used pre-stored
20 surge surface equations which are factory set. Thus, these sysems did not take into account the varying conditions affecting the surge surfaces. The present invention represents an improvement over these three patents, which are all assigned to the same assignee as
25 this application. This invention provides a self-optimizing, capacity control system for inverter-driven centrifugal compressor based water chillers wherein adjustable inlet guide vanes and compressor speed are both automatically regulated in
30 response to a continually updated "learned" chiller surge surface so as to realize the minimum overall chiller energy consumption. This is accomplished by a microprocessor having a random-access memory which periodically identifies the location of the surge surface at
35 the current operating point of the chiller and updates that surge surface information in the random-access

memory during a "learning" mode. Then, the micro-
proc ssor causes the chiller to operate at a safety
margin away from the surge surface during an"operating"
mode for minimum energy consumption.

In particular, the present invention uses all of the
same input signals to the control system block 50 in the
'725 patent except that (1) the condenser temperature
from the thermistor 56 is replaced by an absolute con-
denser pressure signal taken from the transducer 110 on
line 111 of '719 patent and (2) the evaporator tem-
perature from the thermistor 58 is replaced by an
absolute evaporator pressure signal taken from the
transducer 112 on line 113 of the '719 patent. Further,
the amplifier 59 of the '725 patent is replaced by a func-
tional generator 104 formed by the blocks 120 and 123 in
Figure 2 of the '719 patent. The substantial improvement
of the present invention depends in part upon substi-
tuting the electronic circuitry of the control system 50
illustrated in Figure 6A, 6B and 6C of the '725 patent by
a microprocessor having a random-access memory for stor-
ing the updated surge surface information.

Accordingly, it is a general object of the present
invention to provide a self-optimizing capacity control
system for a refrigeration system wherein the compressor
speed and inlet guide vane position are both adjusted
automatically in response to a continually updated
"learned" chiller surge surface so as to realize minimum
overall chiller energy consumption.

It is an object of the present invention to provide
a self-optimizing, capacity control system for a refri-
geration system which includes a microprocessor having a
random-access memory for periodically identifying the
location of the surge surface at the current operating
point and for updatating the surge surface information in
the random-access memory during a "learning" mode.

It is another obj ct of the present invention to
provide a self-optimizing, capacity control system for a

refrigeration system which includes a microprocessor responsive to continual mea:urements of a PRV signal, a compressor head signal, a compressor motor speed signal, and a motor current signal for setting the compressor speed at a safety margin from the surge speed during an "operating" mode.

In accordance with these aims and objectives, the present invention is concerned with the provision of a self-optimizing, capacity control system for a refrigeration system which includes a compressor, condenser and an evaporator, all connected in a closed refrigeration circuit. The compressor has a plurality of adjustable inlet guide vanes, a motor connected to regulate the inlet guide vanes position, and an electrical variable speed motor connected to drive the compressor. The self-optimizing, capacity control system includes means for sensing the absolute condenser pressure to generate a first signal and means for sensing the absolute evaporator pressure to generate a second signal. There are also provided means for sensing the amplitude of the current flowing in the compressor drive motor to generate a third signal and means for sensing the actual speed of the compressor drive motor to generate a fourth signal. Means for sensing the physical position of the inlet guide vanes is provided to generate a fifth signal. Means for sensing the temperature of the chilled water discharged from the evaporator is provided to generate a sixth signal. Further, there is provided a means for sensing a temperature set point to generate a seventh signal. A microprocessor responsive to the first through the seventh signals generates control signals to regulate automatically both the speed of the compressor drive motor and the position of the inlet guide vanes so as to realize minimum overall chiller energy consumption.

These and other objects and advantages of the present invention will become more fully apparent from the following detailed description when read in conjunction with the accompanying drawings with like reference numerals indicating corresponding parts throughout, wherein:

Figure 1 is block diagram of a self-optimizing, capacity control system of the present invention which includes a microprocessor with a RAM;

Figure 2 is a graphical illustration useful in understanding the operation of the present invention in the partly open vane region of a "learning" mode;

Figure 3 is a more detailed diagram illustrating the microprocessor of Figure 1 by way of a flow chart during a "learning" mode;

Figure 4 is a more detailed diagram illustrating the microprocessor of Figure 1 by way of a flow chart during an "operating" mode;

Figures 5 and 6 are graphical illustrations useful in understanding the operation of the present illustration; and

Figure 7 is a graph depicting a typial initial chiller surge surface and an adjusted surge surface.

Referring now in detail to the various views of the drawings, there is shown in Figure 1 in block diagram form a refrigeration or cooling system which includes a centrifugal compressor 20 for passing a refrigerant through line 21 to a condenser 22. Water from a cooling tower (not shown) enters on line 23 and leaves on line 24, the water being in heat exchange relationship with the liquid refrigerant in the condenser 22. A refrigerant at the discharge side of condenser 22 is delivered to a fixed orifice 26 via line 25. The outlet of the orifice 26 is passed over line 27 to the refrigerant inlet connection of an evaporator 28. The refrigerant is then passed through the evaporator and out a suction duct 30

having a plurality of inlet guide vanes 31 or
pr -rotational vanes (PRV). The position of the guide
vanes 31 is regulated by a small PRV motor 32 which
receives a control signal on line 33. The higher tem-
5 perature of water from a building or cooling load (not
shown) enters on line 34 and leaves as chilled water on
line 35, the building water being in heat exchange rela-
tionship with the refrigerant vapor in the evaporator 28.

An electrical prime mover such as an induction motor
10 36 is coupled over a shaft 39 for driving the centrifugal
compressor 20. The motor 36 is in turn driven from an
inverter 37 which receives a DC input voltage over line
38 so as to determine the amplitude of the inverter out-
put voltage. A voltage control circuit 40 is provided
15 between a voltage supply line 41 and the line 38 which
delivers the DC input voltage to the inverter 37. The
frequency of the inverter output voltage is resulted by
the periodicity of timing or gating signals appearing on
line 43 from a logic circuit 44. As is well known, a
20 regulating input signal through the logic circuit on line
45 may be a DC voltage for controlling a
voltage-controlled oscillator in the logic circuit to
provide output pulses at a frequency determined by the
amplitude of the signal on line 45. The logic circuit
25 generally includes a ring counter-type circuit to dis-
tribute the impulses to the switching means such as
thyristors in the inverter 37.

As described thus far, the components of the present
refrigeration system are quite conventional in nature and
30 are the same components as shown in Figure 1 of Patent
No. 4,151,725 which is hereby incorporated by reference.
The substantial improvement of the present invention de-
pends in part upon the provision of a microprocessor 106
with random-access memory (RAM) 107 which is utilized to
35 automatically regulate both the speed of the induction
motor 36 via lin 51 and the physical position of the

pre-rotational vanes 31 via line 33 so as to realize minimum overall chiller energy consumption. The vane control signal on line 33 can be either an "open vanes" signal on line 53 or a "closed vanes" signal on line 54, or no signal ("hold vanes"). As can be seen, the output speed control signal from the microprocessor 106 on line 112 is fed through a digital-to-analog (D/A) converter 114 for supplying the line 51. The vane position control signals from the microprocessor 106 on lines 116 and 118 are fed through respective D/A converters 120 and 121 for supplying the respective lines 53 and 54. These output control signals are derived from various input signals which will now be described.

A first input signal on line 55 is provided by a first compressor transducer 56 and is a function of the absolute pressure in the condenser 22. A second input signal on line 57 is obtained from a second pressure transducer 58 and is a function of the absolute pressure in the evaporator 28. The first input signal is fed through analog-to-digital (A/D) converter 122 for driving the microprocessor 106 via line 124. The second input signal is fed through A/D converter 126 for driving the microprocessor 106 via line 128. The pressure transducers 56, 58 are the same type as pressure transducers 110 and 112 described in Figure 1 of U. S. Patent No. 4,282,719 which is hereby incorporated by reference.

A third input signal on line 71 which is representative of the amplitude of the current flowing through the winding of the induction motor 36. This motor current signal is fed through A/D converter 179 for driving the microprocessor 106 via line 181. This motor current signal may be derived from a current transformer 75 connected to the motor 36 via a line 77. The first, second and third input signals representative of the respective condenser pressure, evaporator pressure and motor current define input signals for surg detctor

means 165 for the chiller of the present invention as will be explained in more detail later.

A fourth input signal on line 72 is provided which is representative of the actual motor speed of the induction motor 36. This motor speed signal is fed to A/D converter 183 for driving the microprocessor 106 via line 184. It should be understood that the actual motor speed can be derived via a conventional tachometer 73 connected to the motor 36 via a line 74.

A fifth input signal on line 62 is provided by a potentiometer 61 with its movable arm or wiper mechanically coupled to the output shaft of the PRV motor 32 as indicated by the dotted lines 61a. Therefore, this fifth input signal indicates (i.e., wide open vanes – WOV, 3/4 open, 1/2 open and so forth) of the inlet guide vanes 31 in a continuous manner. The fifth signal is fed through A/D converter 130 for driving the microprocessor 106 via line 132. A sixth input signal on line 64 is obtained from a thermistor 63 positioned to sense the temperature of the chilled water discharged from the evaporator 28. This sixth signal represents the instantaneous load condition and is fed through A/D converter 134 for driving the microprocessor 106 via line 136. A seventh input signal on line 138 is obtained from a potentiometer 66 and represents a temperature set point or desired condition signal. This seventh signal is fed through A/D converter 140 to the microprocessor 106 via line 142.

In order to provide an understanding of the general overall operation of the present invention, reference is now made to Table I of the Appendix which summarizes how the microprocessor regulates the compressor speed and PRV position in the surge surface during a "learning" mode and during an "operating" mode. As can be seen, there exists a wide open vane (WOV) region and a partly open vane (POV) region for each mode. In the WOV region of

the "learning" mode, there are no surge surfaces to be learned since the PRV are wide open and thus no other combinations exists for a lower speed and more open vane position. Consequently, any reduction in compressor speed will cause a lower chiller capacity and a higher leaving chilled water temperature.

Reference now made to Figure 2 of the drawings which is a graphical illustration useful in understanding the operation of the present invention in the POV region of the "learning" mode. Figure 2 depicts how lines of constant chiller power appear on a chart where the PRV setting is plotted along the left ordinate and the compressor speed is plotted along the abcissa. For example, if the PRV setting is equal to the PRV_i and the compressor speed is equal to S_i, there is defined a particular operating point i. Prior to initiation of "learning mode", the microprocessor will determine the current operating point in an initial surge surface array for the various input signals. The method for generating the initial surge surface array which is stored in a random-access memory (RAM) 107 of the microprocessor 106 will be explained hereinafter.

Upon start-up of the "learning mode", the microprocessor will lower incrementally the compressor speed such as by approximately .1 hz to a point "a". Then, with the speed being held constant the chilled water temperature control is closed by moving of the PRV to a point "b" so that the error in the water temperature is within ±.1○F from the water set point temperature. This process is continually repeated along point "c", "d", "e", and "f" until a surge is detected at the point "f". The current surge surface array stored in the RAM is now updated with the detected surge conditions or information reltive to the PRV position, compressor speed, and pres-sure ratio. Finally, the microprocessor will suspend the

"learning" mode and activate the normal "operating" mode which now will be described.

In the WOV region of the "operating" mode, the PRV are held in a fully opened position and the compressor speed is increased or decreased so as to meet the load requirement by maintaining constant the leaving chilled water temperature. If a reduced load requires a lower capacity, the microprocessor will shift to the partly open vane region of control. In the POV region of the "operating" mode, errors in the chilled water temperature are controlled by changing both the PRV position and the compressor speed. The primary chiller capacity control is accomplished by adjusting the PRV position. The PRV are moved to a more open position if a chiller capacity is increased and to a more closed position if the chiller capacity is decreased.

The secondary chiller capacity control is accomplished by adjusting the compressor speed so as to increase or set it at a safety margin, such as .5 hz to a point "g" in Figure 2, away from the surge speed as determined from the latest surge surface during the "learning" mode. It should be understood that the compressor speed is a function of the PRV position and the head measurement (approximated by the pressure ratio). Thus, this point "g" defines the minimum energy operating point which is surge free and still satisfies the load and head requirements.

The details of the microprocessor required to perform the function just described with respect to the "learning" mode portion of Table I is shown in Figure 3 in a flow chart fashion. The microprocessor 106 includes a functional block 104 which receives the first input signal representative of the absolute condenser pressure from line 124 and the second input signal representative of the absolute evaporator pressure from line 128. The functional block 104 produces on its output line 105 a

signal which is a ratio. This ratio signal is the same as the signal represented on line 124 in Figure 2 of the '719 patent. A block 158 receives this ratio signal on line 105 which is indicative of the compressor head. The input signal representative of the motor speed on the line 184 is also received by the block 158. Further, a fifth input signal representative of the vane position on the line 132 is fed to the block 158.

From all of these inputs a block 160 locates the current operating point such as the point "i" of Figure 2. The surge array is stored in the RAM 107. Once the operating point is located, the compressor speed is incrementally decreased in speed by a speed block 162. This output speed control signal on the line 112 from the block 162 is utilized to regulate the speed of the induction motor 36 via the D/A converter 114 and the line 51.

A block 164 receives the sixth input signal representative of the instantaneous load condition from line 136 and the seventh input signal from line 142 representative of the desired condition. The block 164 is used to increase or open the position of the vanes so that an error between the chilled water temperature and the temperature set point is within point .1ºF.

A surge detector block 166 in response to the surge detection device 165, which is provided as part of the present control system, determines whether the centrifugal compressor is in the surge condition. This surge detection device 165 may be the same the surge detection apparatus 10 of Figure 1 taught in copending application Serial No. 685,686, which was filed on December 24, 1984 in the names of Madeleine M. Lowe and Robert T. Hagerman and assigned to the same assignee as the present invention. In this copending application which is hereby incorporated by reference, the surge detection apparatus 10 receives as input signals a motor current signal

obtained from a current transformer 24 connected in a phase line 26 of an induction motor 20, a condenser pressure signal obtained from a first pressure transducer 32 connected to the discharge line of the condenser 14,

5 and an evaporator pressure signal obtained from a second pressure transducer 34 connected to the suction side of the compressor. The device 165 receives these corresponding input signals on respective lines 181, 124 and 128. In response to these input signals, the apparatus

10 10 generates as output signals a filtered motor current signal on line 63, a filtered differential pressure signal on line 60, a filtered current threshold signal on line 70 and a filtered differential pressure threshold signal on line 72. The device 165 generates these

15 corresponding output signals on lines 167, 169, 171 and 173 which are fed to the microprocessor 106.

The surge detector block 166 in the microprocessor 106 depicted in Figure 3 of the present invention is formed in the manner as the flow chart shown in Figure 2

20 of the aforementioned copending application. Thus, the block 166 will indicate that the compressor is surging when the differential pressure threshold and current threshold signals are exceeded within a pre-selected time interval.

25 If a surge condition does not exist, the process of decreasing the compressor speed is repeated via the block 162 until a surge condition exists. At the surge condition, a block 168 reads the PRV position, condenser pressure, evaporator pressure, and compressor speed.

30 This new information is updated by a block 170 for storing in the RAM 107. Thereafter, blocks 172 and 174 causes discontinuation of the "learning" mode and activates the normal "operating" mode of the system, respectively.

35 Similarly, the details of the microprocessor 106 r quir d to perform the function previously described

with respect to the "operating" mode portion of Table I is shown in Figure 4 in a flow chart fashion. A block 176 increases the compressor speed until the system is no longer in the surge condition. Once it is determined

5 that the compressor is not surging any block 166, a block 178 will open the position of the vanes if the chilled water temperature is determined to be too hot by the "open vanes' control signal on line 116. On the other hand, if the chilled water temperature is too cold, the

10 block 178 will cause the position of the vanes to close by the "closed vanes" control signal on line 118. These same control signals are used to regulate the PRV motor 32 via the line 33. Subsequently, the compressor speed is increased a safety margin such as .5 hz from the

15 current surge speed surface stored in the RAM 107. This is accomplished by the output speed control signal on the line 112 from the block 180 which is utilized to regulate the speed of the induction motor via the DA converter 114 via the line 51.

20 The method of generating the initial approximation to the surge surface for any variable speed chiller will now be explained. It is generally known to those skilled in the art that a Minimum Mach number M_O representative of compressor speed at wide open vanes is a

25 function of the presure ratio over the compressor. The average values of actual measurements obtained from commercially available chillers during experimentation can be plotted to generate the graphical illustration of Figure 5. Further, it is also known that a speed correc-

30 tion referred to as "speed boost"ΔM_O is required to be made in the POV region of control for the minimum Mach number at WOV to formulate correctly the surge surface. Similarily, the average values of actual measurement of "speed boost" and PRV positions can be plotted to

35 generate the graphical illustration of Figure 6. By combining the Mach number relationship from Figures 5

and 6 and defining the Mach number at 60 Hz inverter frequency to be equal to 1.5, the initial surge surface speed array can be generated and shown in Table II of the Appendix. In Table II, the columns are designated by the pressure ration P_{cd}/P_{ev} whle the rows are designated by PRV position with 2.00 volts corresponding to the closed vane position and 10.00 volts corresponding to the wide open vane position. The tabulated surge surface speed are scaled such that 9.99 volts corresponds to 60 hz inverter frequency. Further, this information can be plotted to provide a typical initial surge surface which is illustrated in Figure 7 of the drawings. This initial surge surface is the one stored initially in the RAM 107 of the microprocessor.

The accuracy of this initial surge surface is not required since an updated point on the surge surface will be "learned" during the "learning" mode. From this, the microprocessor will adjust all of the values in the surge surface array and calculate a new surge surface. For example, an adjusted surge surface is shown as a dot-dash line in Figure 7 whch illustrates a surge speed that is above the previously "learned" surface.

For completeness in the disclosure of the above described system but not for purposes of limitation, there is listed in Tabe III the functions of each task for the microprocessor in performing the various control and surge learning and detecting features of the present invention.

From the foregoing detailed description, it can best be seen that the present invention provides a self-optimizing, inverter-driven centrifugal compressor based water chiller control system wherein adjustable inlet guide vanes and compressor speed are both automatically regulated in response to a continually updated "learned" chiller surge surface so as to realize minimum overall chiller en rgy consumption. The control system

of the pres nt invention includes a microprocessor having a random-access memory for storing an updated current surge surface during the "learning" mode. Further, during the "operating" mode the compressor speed is set

5 at a safety margin away from the current surge speed surface.

While there has been illustrated and described what is at present to be a preferred embodiment of the present invention, it will be understood by those skilled in the

10 art that various changes and modifications may be made, and equivalents may be substituted for elements thereof without departing from the true scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the

15 invention without departing from the central scope thereof. Therefore, it is intended that this invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments

20 falling within the scope of the appended claims.

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REGION OF SYSTEM CONTROL	LEARNING MODE		OPERATING MODE	
	COMPR. SPEED	PRV	COMPR. SPEED	PRV
Wide Open Vane "WOV"	No "Learning" mode. A surge is possible as chiller load decreases, forcing an entry into the surge surface functional		Chilled water controlled by Speed	Held open
Party Open Vane "POV"	Decremented in Steps until surge occurs	Chilled water controlled by PRV	Interpolation of latest surge surface functional and safety factor	Chilled water controlled by PRV

TABLE I

APPENDIX

INITIAL SURGE SPEED ARRAY

I	1.80 J=1	2.00 2	2.10 3	2.20 4	2.30 5	2.40 6	2.50 7	2.60 8	2.80 9	3.10 10	3.60=PCD/PEV 11	PRV
1	9.06	9.58	9.82	9.99	9.99	9.99	9.99	9.99	9.99	9.99	9.99	2.00
2	8.66	9.13	9.42	9.65	9.86	9.99	9.99	9.99	9.99	9.99	9.99	2.50
3	8.33	8.35	9.08	9.32	9.53	9.74	9.96	9.99	9.99	9.99	9.99	3.00
4	8.13	8.65	8.83	9.12	9.33	9.54	9.76	9.94	9.99	9.99	9.99	3.33
5	7.93	8.45	8.63	8.92	9.13	9.34	9.56	9.74	9.91	9.99	9.99	3.67
6	7.73	8.25	8.43	8.72	8.93	9.14	9.36	9.54	9.91	9.99	9.99	4.00
7	7.56	8.08	8.32	8.55	8.76	8.98	9.19	9.33	9.74	9.99	9.99	4.33
8	7.43	7.95	8.18	8.42	8.63	8.84	9.06	9.24	9.61	9.99	9.99	4.67
9	7.26	7.78	8.02	8.25	8.46	8.68	8.89	9.03	9.44	9.91	9.99	5.00
10	7.16	7.68	7.92	8.15	8.36	8.58	8.79	8.98	9.34	9.81	9.99	5.50
11	7.06	7.58	7.82	8.05	8.26	8.48	8.69	8.88	9.24	9.71	9.99	6.00
12	6.83	7.35	7.58	7.82	8.03	8.24	8.46	8.64	9.01	9.48	9.99	7.50
13	6.66	7.18	7.42	7.65	7.86	8.08	8.29	8.48	8.84	9.31	9.92	10.00

TABLE II

APPENDIX

TASK OUTLINE FOR SELF-OPTIMIZING CONTROL SYSTEM
======== ============================ =======

TASK 0--Base Initialization Task
  a) Performed only at system start up
  b) Reads Mach No. at 60 hz and a code to initialize the
     surge surface array or use the latest array learned
     for the chiller
  c) Initializes parameters for i/o filters, safety margins,
     etc.
  d) Resets surge detector after inverter reaches 60 hz
  e) Loops until inhibit vane logic from logic board permits
     vane movement
  f) Activates all periodic tasks for control, learning,
     detection of surge, etc.

TASK 1--Normal Control of Compressor Speed
  a) Activated every .5 sec
  b) Computes incremental speed changes due to: 1) Water
     temperature error from set point, 2) Speed error from
     latest learned surge surface, 3) Presence of a closed
     switch to establish a 60 hz operating point
  c) Outputs new speed set point to inverter logic board

TASK 2--Normal Control of PRV Movement
  a) Activated every 10 sec
  b) Computes period for the PRV vane motor contacts to be
     closed depending on current PRV location and water
     temperature error

TASK 3--Test For Compressor Surge
  a) Activated every 1. sec
  b) Tests for the surge detector logic signal indicating
     the chiller is in a surging state
  c) Kills Tasks 1 and 2
  d) Activates a subroutine to exit from surge by increasing
     speed and reducing PRV position
  e) Activates a subroutine to update that surge in the
     stored surge surface array in the computer memory
  f) Reactivates Tasks 1 and 2

TASK 4--Probes For Surge Surface
  a) Kills Tasks 1 and 2
  b) Locates start of surge surface probe in the stored array
  c) Increases PRV, if water temperature allows, by an
     increment if vanes are already not wide open
  d) Decreases speed, if speed is not at its minimum
  e) Reactivates Tasks 1 and 2 for normal control, if the
     PRV are at their maximum opening or if the speed is
     at its minimum, and updates the surge surface
  f) Continues looping of this task until tests of e) are
     satisfied or the system surges

TASK 5--Defines and Activates TASK 4

TASK 6--Reads and Filters Input Variables
  a) Activated every .5 sec
  b) Reads and filters (via a first order lag with time
     constant of 2 sec): 1) Water set point temperature,
     2) Actual water temperature, 3) Condenser pressure,
     4) Evaporator pressure, 5) Compressor speed, 6) PRV
     position
  c) Computes the water temperature after a lead/lag control
     compensation software section

TABLE III

APPENDIX

CLAIMS

1.   A self-optimizing, capacity control system for a refrigeration system, including a compressor (20), a condenser (22), and an evaporator (28), all connected in a closed refrigeration circuit, which compressor includes a plurality of adjustable inlet guide vanes (31), a motor (32) connected to regulate the inlet guide vanes position, and an electrical variable speed motor (36) connected to drive the compressor, said control system comprising:

means (56) for sensing the absolute condenser pressure to generate a first signal;

means (58) for sensing the absolute evaporator pressure to generate a second signal;

means (75) for sensing the amplitude of the current flowing in the compressor drive motor to generate a third signal;

means (73) for sensing the actual speed of the compressor drive motor to generate a fourth signal;

means (61) for sensing the physical position of the inlet guide vanes to generate a fifth signal;

means (63) for sensing the temperature of the chilled water discharged from the evaporator to generate a sixth signal;

means (66) for sensing a temperature set point to generate a seventh signal; and

microprocessor means (106) responsive to said first through seventh signals to generate control signals to regulate automatically both the speed of the compressor drive motor and the position of the inlet guide vanes based upon a continually updated "learned" chiller surge surface so as to realize a minimum overall chiller energy consumption.

2.   A capacity control system as claimed in Claim

1, wherein said condenser pressure sensing means comprises of a first pressure tranducer (56).

3.   A capacity control system as claimed in Claim 1, wherein said evaporator pressure sensing means comprises a second pressure transducer (58).

4.   A capacity control system as claimed in Claim 1, wheren said inlet guide vanes sensing means comprises a potentiometer (61) having a movable arm mechanically coupled to the shaft of the vanes position motor.

5.   A capacity control system as claimed in Claim 1, wherein said current sensing means is a current transformer (75).

6.   A capacity control system as claimed in Claim 1, wherein said speed sensing means comprises a tachometer (73).

7.   A capacity control system as claimed in Claim 1, wherein said microprocessor means (106) in response to said first through seventh signals determines both the compressor speed and the position of the inlet guide vanes to define a current operating point in an initial surge surface array stored in a random-access memory (107).

8.   A capacity control system as claimed in Claim 7, wherein said microprocessor means (106) includes means for initiating a "learning" mode in which the compressor motor speed is decreased incrementally and the inlet guide vanes are moved to a more open position to define a second operating point, said microprocessor means determining whether said compressor is surging at said second operating point.

9.   A capacity control system as claimed in Claim 8, wherein said microprocessor means (106) includ s m ans for continually decreasing incrementally the compressor drive motor speed and opening more of the vanes until an operating point is found where said compressor is surging, said microprocessor means updating the initial surge surface array stored in the random-access memory with the latest surge conditions.

10.   A capacity control system as claimed in Claim 9, wherein said microprocessor means (106) includes means for initiating an"operating" mode in which the guide vanes are moved in response to a temperature error signal related to the difference between the sixth and seventh signals and said compressor speed is set at a safety margin away from the surge speed.

11.   A self-optimizing, capacity control system for a refrigeration system including a compressor (20), a condenser (22), and an evaporator (28), all connected in a closed refrigeration circuit, which compressor includes a plurality of adjustable inlet guide vanes (31), a motor (32) connected to regulate the inlet guide vanes position and an electrical variable speed motor (36) to drive the compressor, said control system comprising:

means (104) for generating a first signal which is a function of the ratio of the absolute condenser pressure and the absolute evaporator pressure to define a compressor head signal;

means for generating a second signal which is a function of the amplitude of the current flowing in the compressor drive motor (36) to define a motor current signal;

means for generating a third signal which is a function of the actual speed of the compressor drive motor (36) to define a motor speed signal; and

microproc ssof means (106) responsive to said compressor head signal, motor current signal, and motor speed signal for g nerating control signals to automatically adjust both the speed of the compressor speed drive motor and the inlet guide vanes based upon a continually updated "learned" chiller surge surface so as to utilize minimal overall chiller energy consumption.

12. A capacity control system as claimed in Claim 11, wherein said microprocessor means (106) in response to said first through third signals determines both the compressor speed (20) and the position of the inlet guide vanes to define a current operating point in an initial surge surface array stored in a random-access memory.

13. A capacity control system as claimed in Claim 12, wherein said microprocessor means (106) includes means for initiating a "learning" mode in which the compressor motor speed (36) is decreased incrementally and the inlet guide vanes (31) are moved to a more open position to define a second operating point, said microprocessing means determining whether said compressor is surging at said second operating point.

14. A capacity control system as claimed in Claim 13, wherein said microprocessor means (106) includes means for continually decreasing incrementally the compressor drive motor speed (36) and opening more of the vanes (31) until an operating point is found where said compressor is surging, said microprocessor means updating the initial surge surface array stored in the random-access memory (107) with the latest surge conditions.

15. A capacity control system as claimed in Claim

14, wherein said microprocessor means (106) includes means for initiating an "operating" mode in which the guide vanes (31) are moved in response to a temperature error signal related to the difference between a chilled water temperature and a temperature set point and said compressor speed (20) is set at a safety margin away from the surge speed.

16.   A method for controlling a refrigeration system having a compressor, a condenser, and an evaporator, all connected in an enclosed refrigeration circuit, which compressor includes a plurality of adjustable inlet guide vanes, a motor connected to regulate the inlet guide vanes position and an electrical variable speed motor connected to drive the compressor, said method comprising the steps of:

sensing the absolute condenser pressure to generate the first signal;

sensing the absolute evaporator pressure to generate a second signal;

sensing the amplitude of the current flowing in the compressor drive motor to generate a third signal;

sensing the actual speed of the compressor drive motor to generate a fourth signal;

sensing the physical position of the inlet guide vanes to generate a fifth signal;

sensing the temperature of the chilled water discharged from the evaporator to generate a sixth signal;

sensing a temperature set point to generate a seventh signal; and

generating control signals in response to the first through seventh signals to regulate automatically both the speed of the compressor drive motor and the
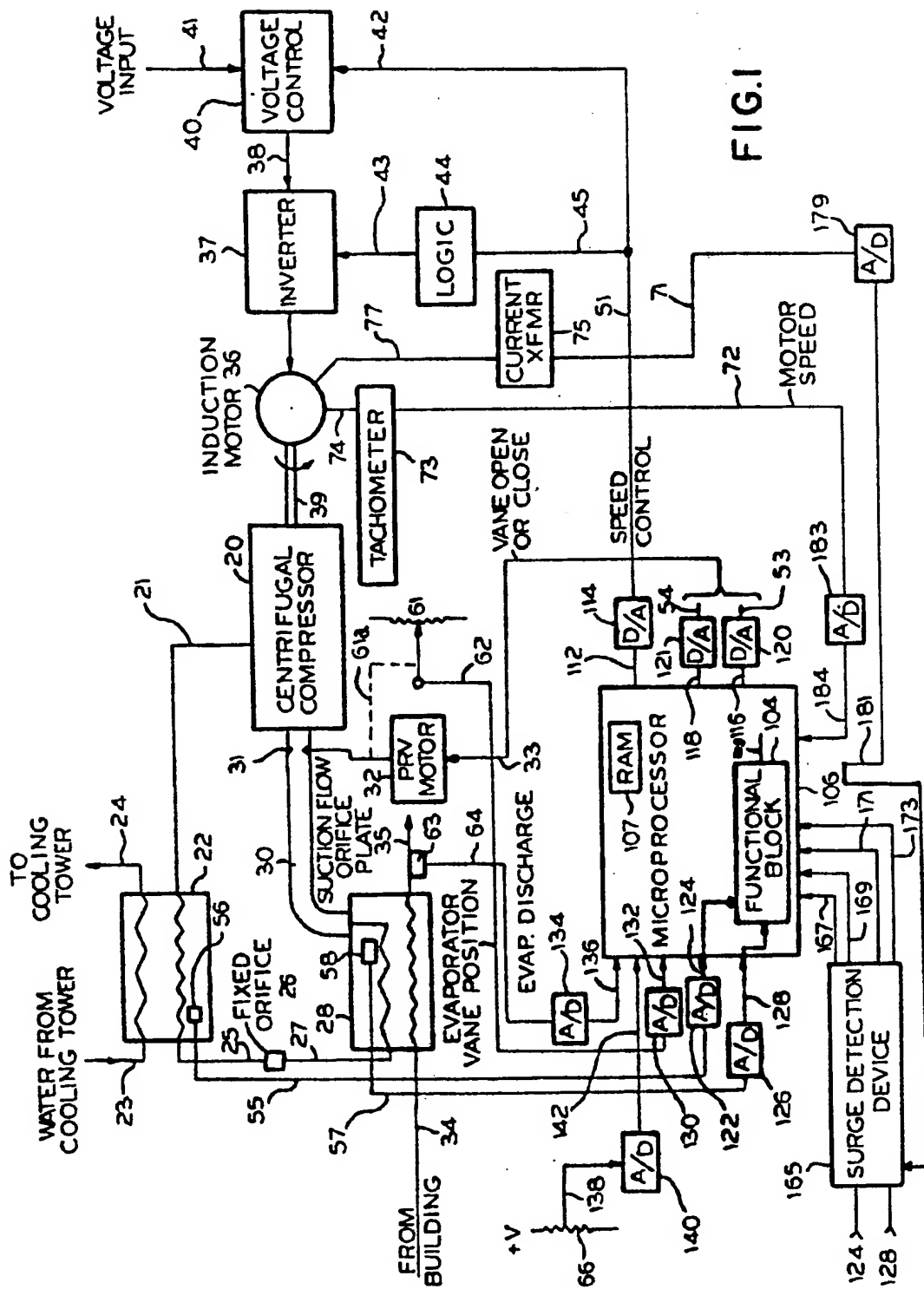
position of the inlet guide vanes based upon a continually updated "learned" chiller surge surface so as to realize minimal overall chiller energy consumption.

17. A method for controlling a refrigeration system as claimed in Claim 16, further comprising the step of determining both the compressor speed and the position of the inlet guide vanes to define a current operating point in an initial surge surface array stored in a random-access memory in response to the first through seventh signals.

18. A method for controlling a refrigeration system as claimed in Clam 17, further comprising the steps of initiating a "learning" mode in which the compressor motor speed is decreased incrementally and the inlet guide vanes are moved to a more open position to define a second operating point, and determining whether said compressor is surging at said second operating point.

19. A method for controlling a refrigeration system as claimed in Claim 18, further comprising the steps of continually decreasing incrementally the compressor drive motor speed and opening more of the vanes until an operating point is found where said compressor is surging, and updating the initial surge surface array stored in the random-access memory with the latest surge conditions.

20. A method for controlling a refrigeration system as claimed in Claim 19, further comprising the step of initiating an "operating" mode in which the guide vanes are moved in response to a temperature error signal related to the difference between the sixth and seventh signals and said compressor speed is set at a safety margin away from the surge speed.
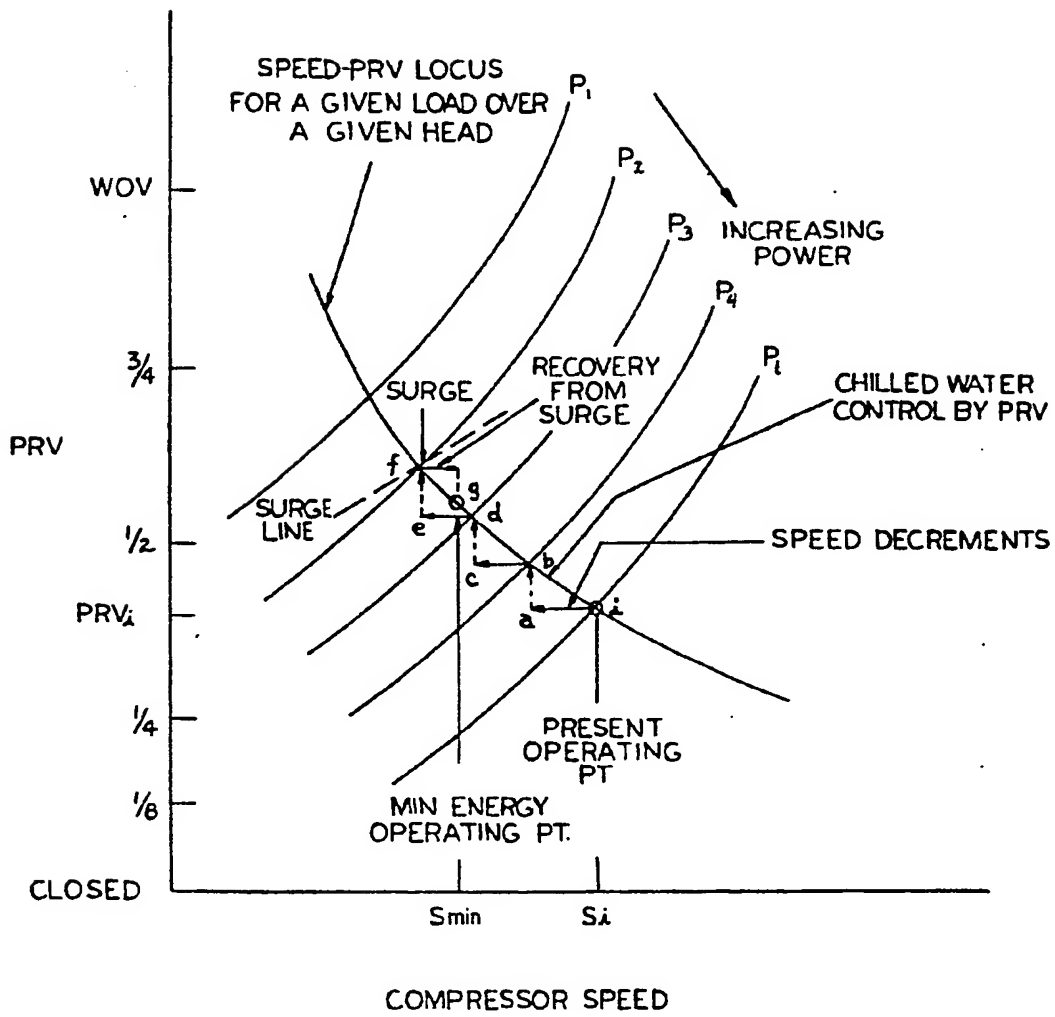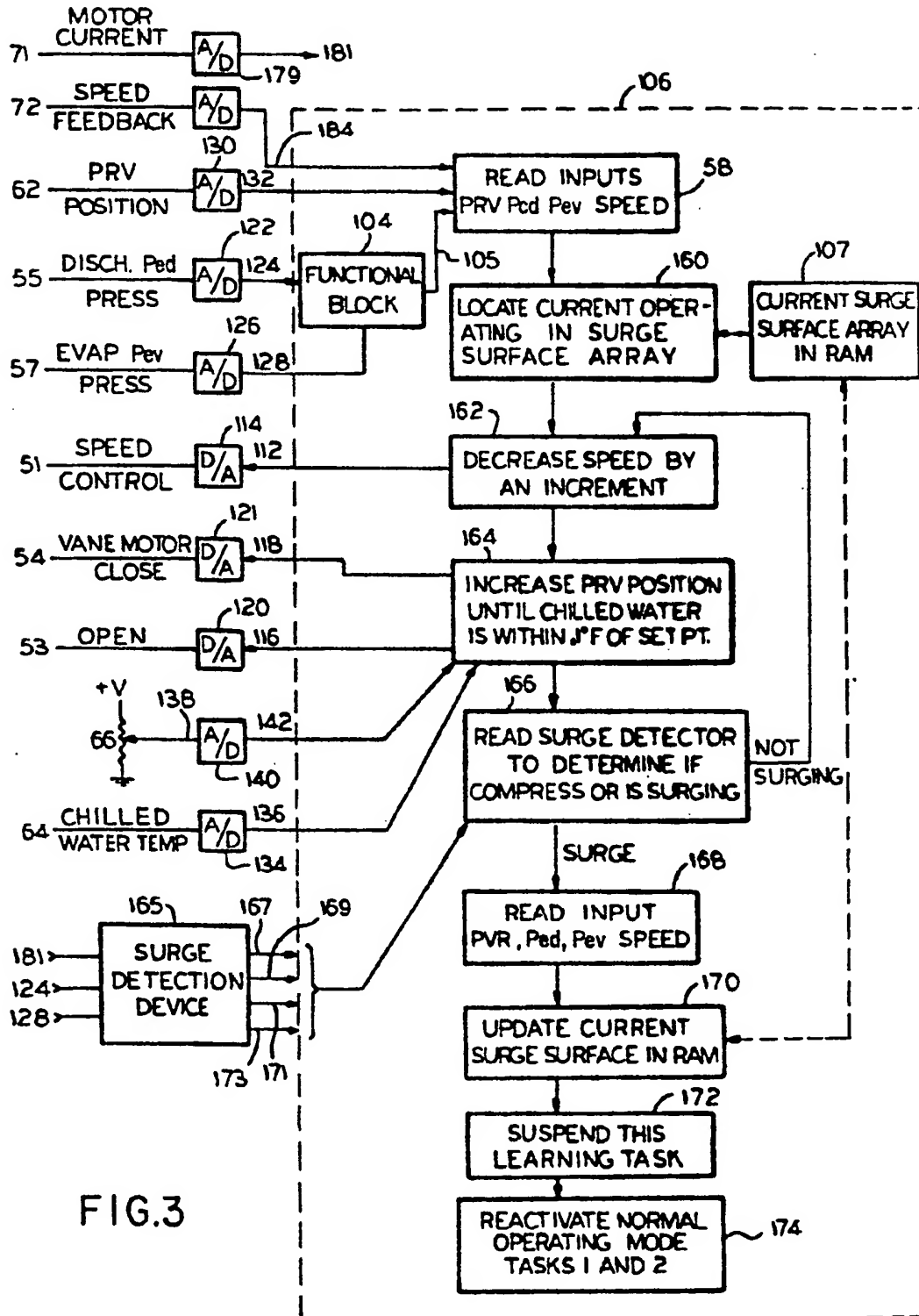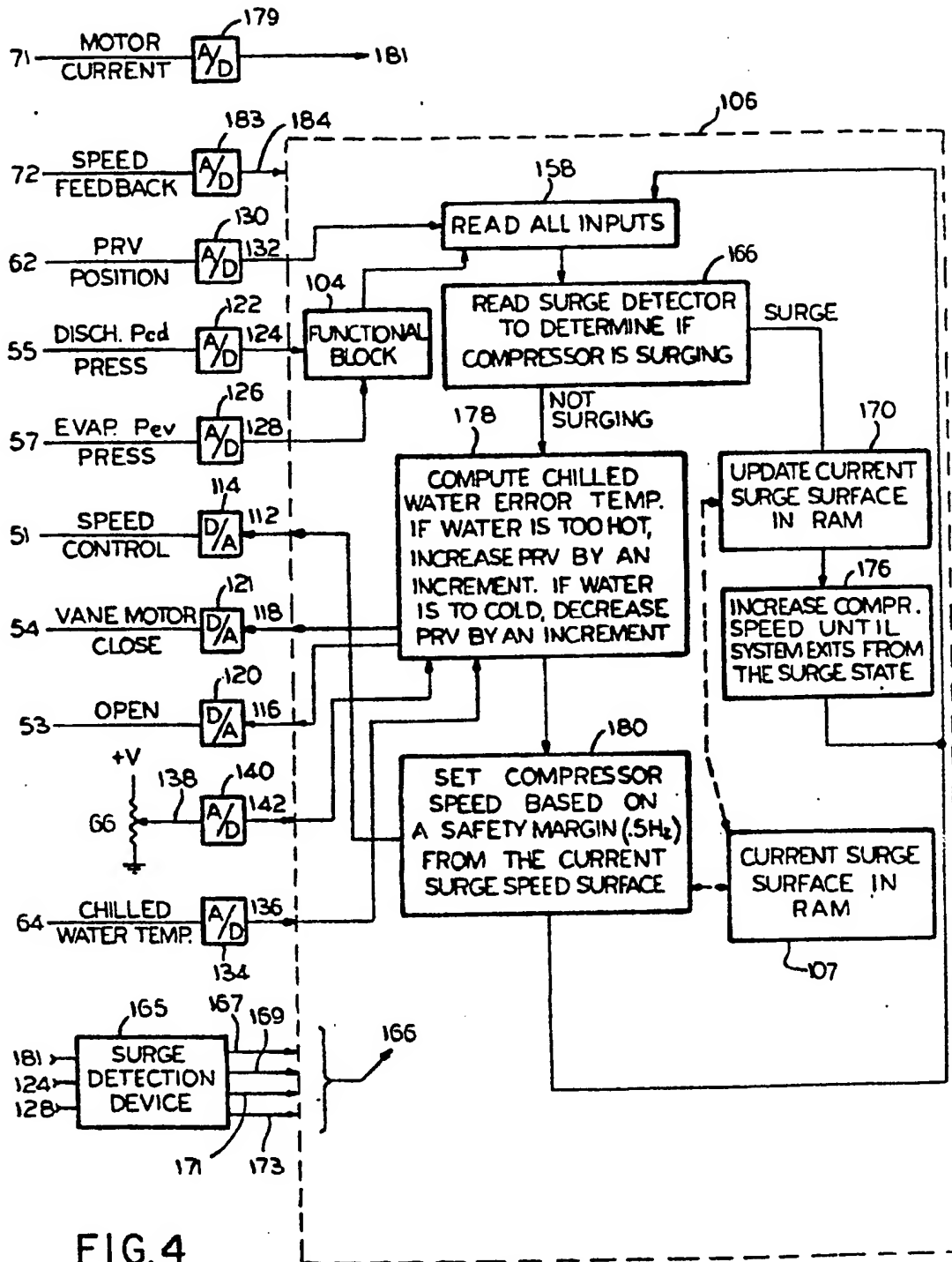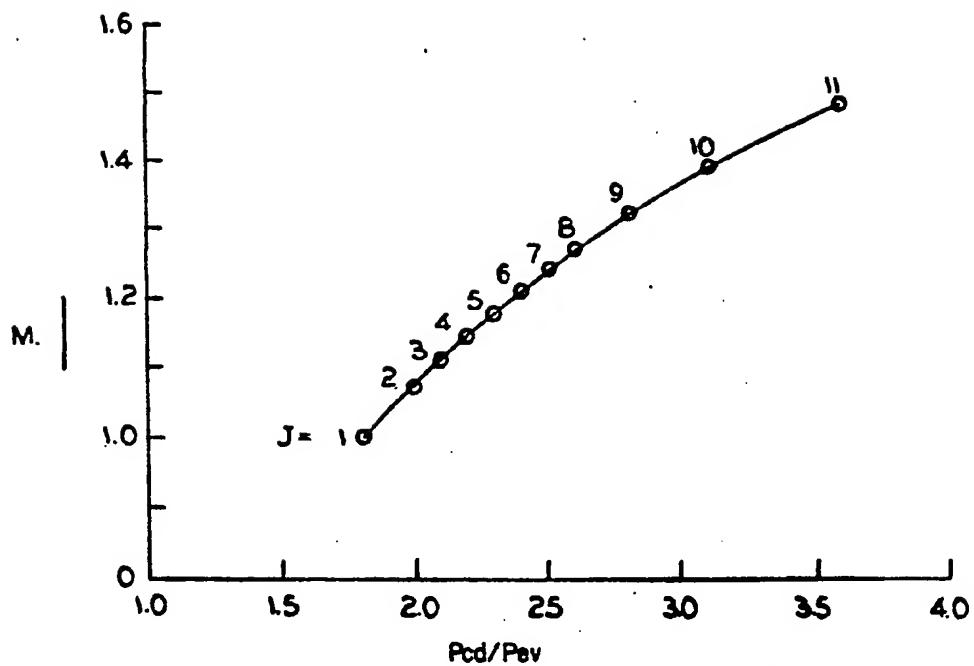
FIG.1
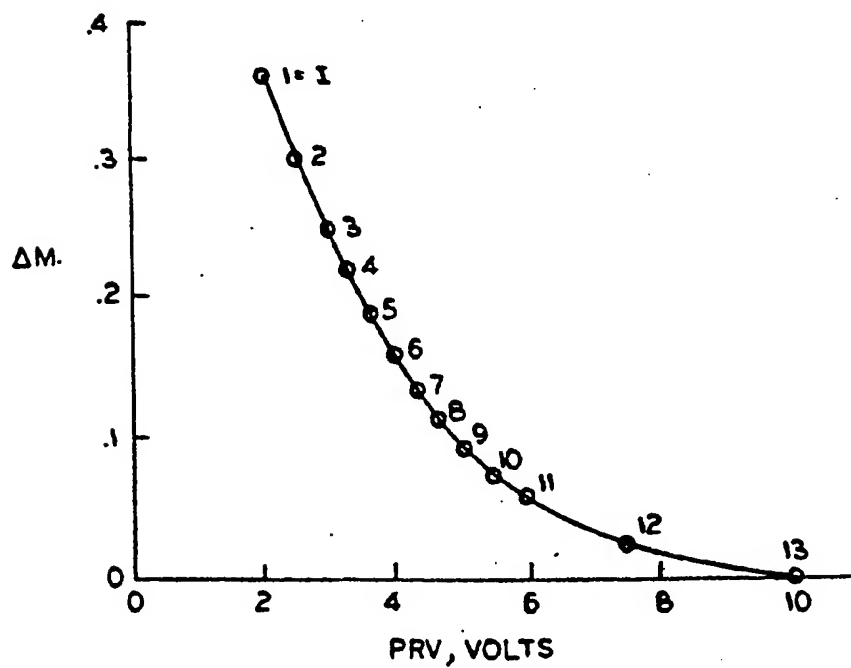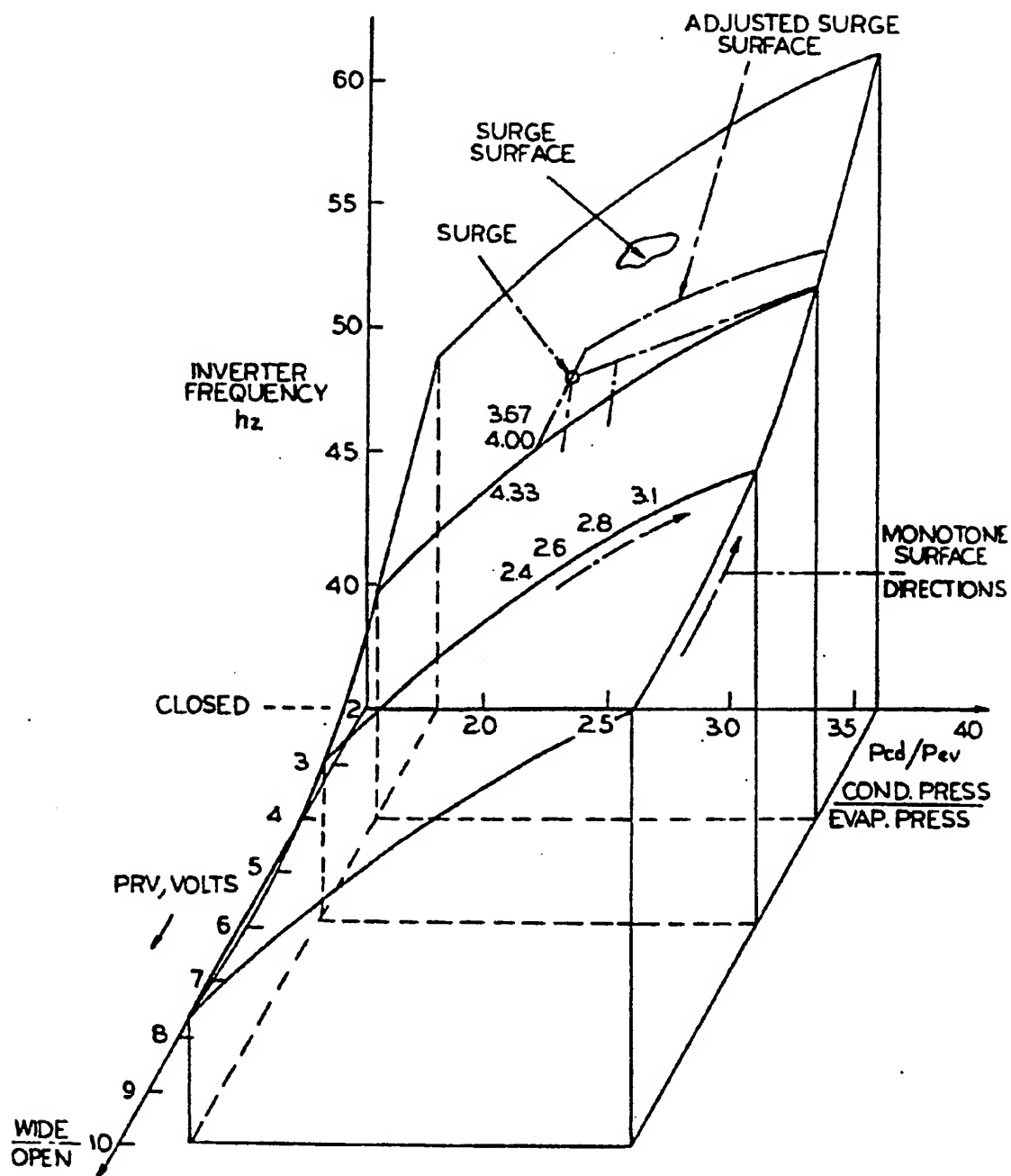
FIG.2

FIG.3

FIG.4

FIG.5

FIG.6

FIG.7

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,A	US-A-4 151 725 (K.J. KOUNTZ et al.) * Figures 1-4; abstract *	1,4-7, 10,11, 16,17, 20	F 04 D 27/02 F 25 B 49/00
D,A	US-A-4 282 719 (K.J. KOUNTZ et al.) * Figures 1-4; abstract *	1-6,11 ,12,16 ,17	
D,P A	US-A-4 546 618 (K.J. KOUNTZ et al.) * Abstract; figures 1,3,4,6 *	1-6,11 ,12,16 ,17	

TECHNICAL FIELDS
SEARCHED (Int. Cl.4)

F 04 D
F 25 B
F 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17-03-1986	THIBO F.